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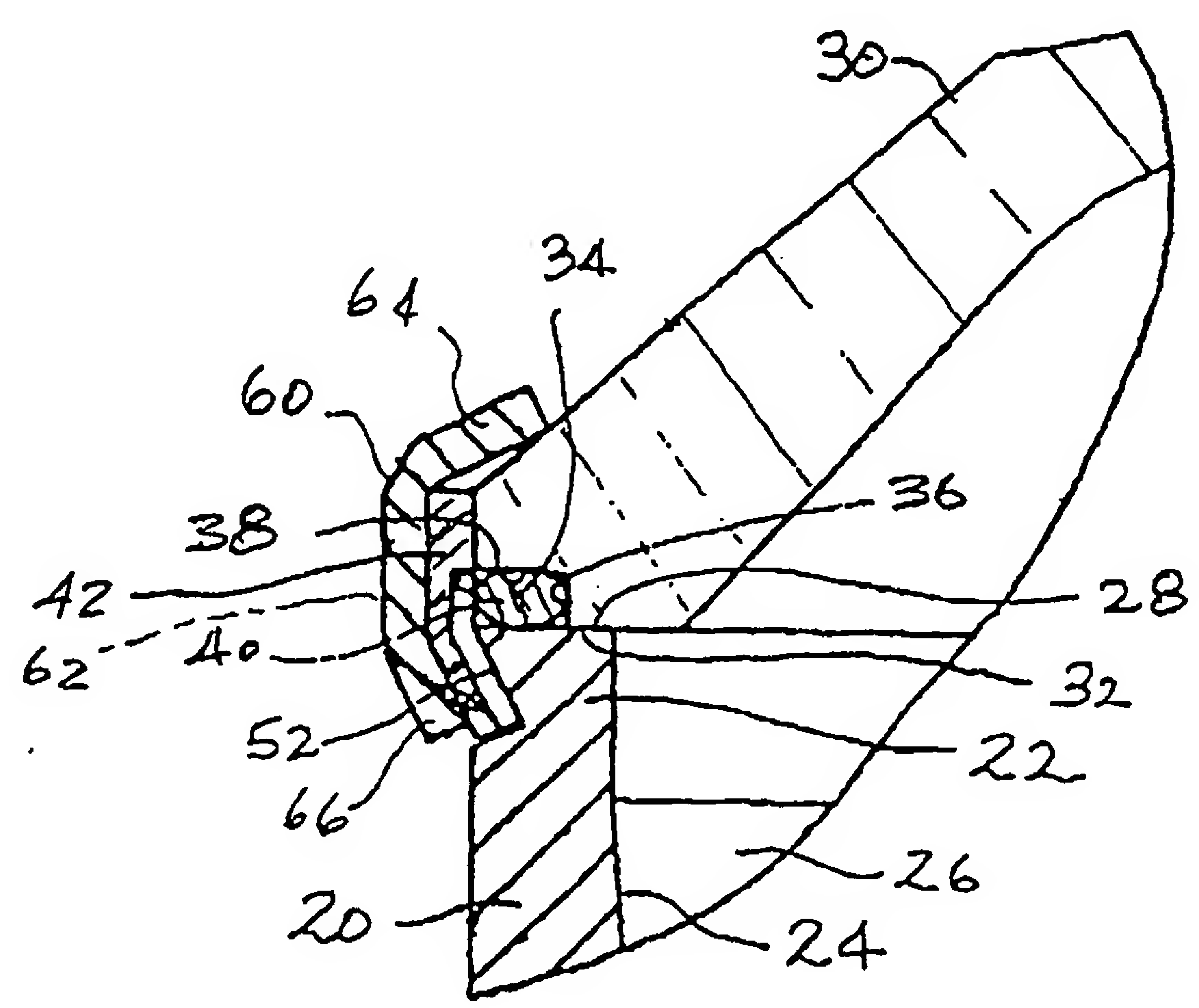
(54) Title: ENCAPSULATED SHAPED CHARGE FOR WELL PERFORATION



(57) Abstract: A hermetically sealed, fully expendable shaped perforating charge (10) consisting of a charge case (12) defining an internal chamber (26) containing an explosive shaped charge. A cap (30) is secured to the case (12) and, for enhanced fracturing, may be composed of ceramic material. Alternatively, the cap (30) may be composed of metal, polymer or composite materials that define fracture grooves (102) forming stress concentration points or lines for controlled fracturing thereof by the explosive jet of the charge so that the fragments are sufficiently small that they will not impede well construction or servicing. The cap (30), regardless of its composition, may be clamped to the case (12) by a crimp ring (60) that is applied over a thermoplastic release member (42) and an elastomer seal ring (40) which establishes sealing between the case (12) and cap (30) to exclude well pressure from the internal chamber (26) of the case (12) and cap (30). The yieldable pressure release ring (60) permits excess internal out-gassing pressure within the internal chamber to bleed off through bleed slots (54), averting a violent ejection of the cap (30) from the case (12) should the gun be retrieved from the well unfired.

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ENCAPSULATED SHAPED CHARGE FOR WELL PERFORATION

BACKGROUND OF THE INVENTION

FIELD OF THE INVENTION:

This invention relates generally to well perforating guns having a plurality of encapsulated shaped explosive charges which are run into a well casing or well bore liner to a desired depth for communication with one or more petroleum production zones of the surrounding earth formation and fired to perforate the well casing to thus admit petroleum products, such as natural gas, crude oil and water into the well casing for production. More particularly, the present invention is directed to the provision of a novel encapsulated shaped charge which, when fired, causes the cap thereof to be fractured into a multiplicity of small pieces or a granular form which will not agglomerate with other well constituents and will not tend to create an obstruction within the well casing or the production tubing, control valves and other components of the well. Even more particularly, the present invention is directed to an encapsulated shaped explosive charge having a casing and closure cap that have the capability of releasing gas pressure in the event excessive heat is encountered, so that the potential for unintended heat induced detonation of the shaped charge during its storage, handling or transportation is significantly minimized.

DESCRIPTION OF THE PRIOR ART:

Encapsulated shaped charges mounted in perforating gun devices are used extensively to perforate oil and gas wells by passing the perforating guns through the production tubing of the well and positioning the perforating gun at a suitable depth and location within the well casing or well bore liner matching the depth or location of one or more production zones intersected by the well bore that has been drilled. Typically, the well casing or well bore liner will have been cemented in place so that the annulus between the wellbore in the earth formation and the external surface of the well casing is filled with hardened cement. Thus, to establish communication via the perforations between the well casing and the production zone of the petroleum

product bearing earth formation, it is necessary that the perforations extend through the wall structure of the well casing and through the cement annulus and a sufficient distance into the earth formation of interest. When properly formed, these perforations, though small in diameter, establish significant formation surface area that expected petroleum product volume is achieved. In addition,, while not very common, perforating guns may be used to create perforations in uncased holes (or open holes), wherein the well bore does not include a casing or liner.

The encapsulated explosive charges of typical perforating guns are quite small in dimension so that the perforating gun with all of its charges can be passed through standard production tubing. Moreover, the perforating charges of a typical perforating gun are phased at differing angles so that the perforations caused by individual shaped charges radiate in differing directions from the gun structure or strip and thus establish perforations in the well casing, cement and formation at differing angular orientations, such as indicated in U. S. Patents Nos. 4.951,744 of Rytlewski, 5,095,999 of Markel and 5,544,711 of Aitken, et al.

"Through tubing" perforating guns are small in diameter relative to the well casing, limiting the explosive powder load that is available for explosive preparation; consequently the penetration and phasing of the perforated holes as well as the amount and type of debris left in the well by the detonating perforating gun are important considerations.

Small diameter "through tubing" perforating guns utilizing encapsulated explosive charges are typical of two general types: In one type of perforating gun, the encapsulated explosive charges are linked together as a chain leaving as debris in the well all of the metallic material in the perforating gun. Link-type perforating guns configured in a spiral firing pattern lose efficiency on the particular explosive charge shots that must fire across large diameter fluid filled casings before penetrating the formation surrounding the well casing.

The second general type of "through tubing" perforating gun utilizes in-line firing charges that are mounted on explosive resistant steel carrier strips having the capability of withstanding the explosive detonation of the charges and remaining

intact so that the carrier strips may be retrieved after casing perforation activity has been accomplished. For the reason that the steel carrier strips are retrieved after firing of the perforating gun, thus only the debris of the charge cases will remain in the well after the perforating gun has been fired and retrieved. In-line strips are positioned in the well casing so that all of the charges fire with zero clearance directly into the casing, maximizing the diameter of the perforated holes in the casing and penetration of the explosive energy into the formation, yielding in general better penetration and possibly higher productivity than wells perforated with spiral phased through tubing type perforating guns. More recently, a through tubing strip gun has been developed, as indicated by US Patent #5095999 of Markel and Patent #5544711 of Aitken. These patents disclose an explosive resistant carrier strip which is configured to orient explosive charges so that the penetration jets of the charges are directed 45 degrees apart. Thus, when this type of strip gun establishes a line of contact with the well casing, each of the explosive charges is oriented at plus or minus 22.5 degrees from the line of contact. This type of two-phased through tubing perforating gun establishes a 90 degree shot pattern which offers some advantage over the single phased in-line configuration that is normal with most strip guns.

The explosive charges of a typical perforating gun are quite small to enable them, when assembled with the recoverable strip of the strip gun to pass through a conventional production tubing string so that the perforating gun can be positioned in contact with the well casing, or very close thereto, at a well depth that is below a packer sealing the production tubing string to the well casing. The small explosive charges however are packed tightly with powerful loads of explosive material which is shaped to define a concave, typically somewhat conical recess therein. As the explosive charge is ignited, the conical recess configuration of the explosive charge causes the development of a very concentrated and specifically oriented explosive jet with sufficient explosive force to penetrate the well casing and the cement annulus surrounding the well casing and also penetrate well into the formation to be produced.

When the shaped explosive charges are properly designed and the explosive charge itself explodes according to its designed characteristics, the typically steel or

other metallic material of the charge cases which are in close contact with the explosive material will be fragmented into small chips or pieces which gravitate to the bottom of the well below all prospective zones of production. In some cases however, especially when the metallic charge caps are not in direct contact with the explosive, the caps may remain essentially intact or may be fractured into fairly large sections as the result of perforation gun detonation. These caps or cap sections may agglomerate with other debris within the well, creating an obstruction to well production. The presence of these caps or large cap sections within the well may prevent or interfere with future well construction or other well service operations below this point in the well. It is desirable therefore to provide a perforating gun having multiple encased explosive charges that are phased, i.e., oriented according to designed well perforation and having individual shaped charges that are designed to ensure that the explosive detonation causing perforation of the well casing or wellbore liner also causes the charge case and front caps of the charge to be fractured into a multitude of very small fragments that will descend to the bottom of the well and will not interfere with other well servicing or construction operations.

The multiple shaped charges of a perforating gun typically are defined by a case structure having an internal cavity defining a generally conical shaped receptacle within which the explosive composition is packed. To the case is assembled a cap with assembly being accomplished in the presence of a circular sealing element establishing efficient sealing between the case and the cap. In some cases, the sealing element is arranged to release internal pressure which might develop within the sealed case responsive to conditions of heat induced out-gassing of the explosive composition or leakage of well gases under pressure into the hollow cavity of the charge. This pressure releasing capability can be important when perforating guns are removed from a well unfired, after having been heated by the elevated temperature of the well at perforation depth. As a perforating gun is retrieved from the well unfired, the pressure relieving capability of the seal and pressure relief ring ensures that the internal pressure within the explosive containing cavity is substantially equalized with atmospheric pressure so that there is no tendency for the front cap to be forced from

the charge case by pressure differential. The charge case and cap assembly, including the sealing element for sealing the cap to the charge case, are also designed to be non-porous, so that leakage of external well pressure into the hollow, explosive containing cavity of the shaped charge will not occur. This feature minimizes any tendency for the cap to be forcibly ejected from the charge case by excess internal pressure when unfired charges are removed from a well.

In the past, both the cap and cases of encapsulated shaped charges for well casing perforation have been manufactured from pure alumina ceramic which is highly impermeable, is quite resistant to abrasion and can sustain high well pressures and temperature. The performance of these ceramic encased charges has proven to be significantly lower than steel cased charges. Additionally encapsulated shaped charges composed entirely of ceramic material have been determined to be difficult to manufacture and they have been found to be very costly from the standpoint of manufacture. It is desirable, therefore to provide encapsulated shaped charges for well casing perforation which take advantage of the characteristics of steel or other similar metal materials to define the shaped charge case and which also accommodate the essentially pulverizing characteristic of ceramic cap structures upon explosive detonation, to thus minimize the dimension of fracture debris that falls to the bottom of the wellbore after casing perforation has taken place.

SUMMARY OF THE INVENTION

It is a principal feature of the present invention to provide a novel shaped charge construction for well perforation guns which ensures fracture of the cap structure of a shaped charge into a multiplicity of small pieces of sufficiently small dimension that they will descend to the bottom of the well and will not interfere with subsequent well service or construction operations;

It is another feature of the present invention to provide a novel shaped charge construction for well perforation guns having a charge case and a cap which are sealed with respect to invasion by well fluids and which will release excessive internal chamber pressure resulting from heat induced out-gassing of the explosive, to thus

prevent the cap from being forcibly ejected from the charge case if the perforating gun is removed from the well in an unfired condition;

It is an even further feature of the present invention to provide a novel encapsulated shaped charge construction for well perforation guns having a charge case and end cap retained in sealed assembly and having the capability for release of the sealed condition of the charge case and end cap when the charge is subjected to fire or elevated heat, to minimize the pressure to which the explosive charge is subjected and to thus minimize the potential for detonation of the explosive composition;

It is another feature of the present invention to provide a novel encapsulated shaped charge construction for the perforating charges of well perforation guns, having a shaped charge case and cap construction composed of any suitable material, with the cap being appropriately scored by fracture grooves that are oriented in a manner causing the cap to be fractured along the fracture grooves so that the remaining fragments thereof are sufficiently small to minimize the potential for interference with well servicing and construction operations; and

It is also a feature of the present invention to provide a novel encapsulated shaped charge construction for the perforating charges of well perforation guns having a shaped charge case and end cap assembly which permits heat responsive separation of the end cap from the charge case in response to excessive heat to permit the explosive composition to be burned rather than detonate.

Briefly, the various objects and features of the present invention are realized by the provision of a hermetically sealed, fully expendable shaped perforating charge consisting of a charge case composed of steel or other suitable material which defines an internal chamber. The charge case contains a highly compressed explosive shaped charge that is designed for the development of a small, specifically oriented explosive jet for perforating a well casing upon detonation and penetrating through the well casing, through the cement in the annulus between the well bore and the well casing and also penetrating a desired distance into the formation to be produced. In one form of the invention, the charge case is closed to well fluids by a cap that is clamped to the

charge case by a circular crimp ring. The crimp ring is applied over a thermoplastic pressure release ring member which is encircled about an elastomer sealing element that establishes sealing between the case and cap to exclude well pressure from the internal chamber of the case and cap. The thermoplastic pressure release ring defines at least one and preferably a plurality of vent or bleed slots which permit internal pressure of the chamber being released by the elastomer seal to bleed past the thermal release ring, averting a violent ejection of the front cap should the gun be retrieved from the well unfired. The thermoplastic pressure release ring maintains the cap securely to the charge case but will melt, in the event that the gun or charges in transit or storage are subjected to extremely high temperature, such as in the case of a fire, releasing the front cap as the explosive begins to out-gas, permitting release of the gas pressure and permitting burning but avoiding detonation of the explosive composition constituting the shaped charges involved.

In an alternative embodiment of the present invention a low melting metal alloy crimp ring provided with internal pressure relief slots, is crimped about the joint between the charge case and the ceramic front cap, thus securing the ceramic cap to the charge case and activating the elastomeric interference seal sealing the ceramic end cap to the charge case. The melting point of the crimp ring alloy is adjusted to suit the out-gassing temperature of the explosive used in the charge, i.e., approximately 400 degrees F for RDX, approximately 500 degrees F for HNS or PYX commonly used in well perforation shaped charges. Thus, the low melting temperature alloy crimp ring will function efficiently to retain the end cap and charge case in sealed assembly under normal use in a well, but in the event of excessive heat, such as in the case of a fire, the crimp ring will be melted and will release the end cap from the charge case and thus permit release of excessive out-gassing pressure, so that the explosive composition will burn but will not detonate.

In accordance with the principles of the present invention a shaped charge case and cap is employed in assembly to define a sealed shaped charge for well perforation guns. To ensure that the cap is fractured into sufficiently small pieces by detonation of the explosive composition within the charge case, the cap is manufactured with a

plurality of fracture grooves which define a geometric fracture pattern. The explosive detonation will cause the cap to fracture along the fracture pattern and will thus cause the resulting cap particles or sections to be sufficiently small that they will not interfere with subsequent well construction or servicing operations.

BRIEF DESCRIPTION OF THE DRAWINGS

So that the manner in which the above recited features, advantages and objects of the present invention are attained and can be understood in detail, a more particular description of the invention, briefly summarized above, may be had by reference to the preferred embodiment thereof which is illustrated in the appended drawings, which drawings are incorporated as a part hereof.

It is to be noted however, that the appended drawings illustrate only a typical embodiment of this invention and are therefore not to be considered limiting of its scope, for the invention may admit to other equally effective embodiments.

In the Drawings:

Fig. 1 is a view in plan, with a part thereof broken away and shown in section, illustrating an encapsulated explosive shaped charge which is constructed in accordance with the principles of the present invention and which is designed for use in a perforating gun for perforating the casing or liner of a well;

Fig. 2 is a sectional view of the broken away section of Fig. 1, illustrating the charge case and cap assembly in greater detail;

Fig. 3 is a partial sectional view showing the original configuration of the pressure relief ring prior to crimped retention thereof in assembly with the encapsulated shaped charge structure;

Fig. 4 is a partial sectional view showing the retained configuration of the pressure release ring and further showing the relationship thereof to the charge case and front cap structures;

Fig. 5 is a fragmentary sectional view of the sealing and pressure relief structure of the encapsulated explosive shaped charge of the present invention and

showing internal pressure responsive movement of the O-ring seal for relief of excess internal pressure;

Fig. 6 is another view in plan, showing an alternative embodiment of the present invention, with a part thereof broken away and shown in section, illustrating an encapsulated explosive shaped charge which is designed for use in a perforating gun for perforating the casing or liner of a well;

Fig. 7 is a sectional view showing the crimp ring of the embodiment of Fig. 5, prior to crimping thereof;

Fig. 8 is an end view of the crimp ring of Fig. 7;

Fig. 9 is a sectional view of the broken away section of Fig. 6, showing the crimped condition of the crimp ring and further showing retention by the crimp ring of a front cap of the explosive shaped charge with vent grooves or slots of the crimp ring associated with a seal ring to permit release of internal pressure due to out-gassing of the explosive composition of the shaped charge;

Fig. 10 is a fragmentary sectional view of an alternative embodiment of the charge case and cap structures showing a circular seal groove that is cooperatively defined by circular tapered surfaces of the case and cap;

Fig. 11 is a fragmentary sectional view of an alternative embodiment of the charge case and cap structures showing a circular seal groove that is defined by a circular recess in the charge case and a planar surface of the cap;

Fig. 12 is a plan view of a cap for a shaped charge case and cap assembly, wherein the cap defines a plurality of fracture grooves for ensuring fracture of the cap into a multiplicity of small pieces or sections responsive to the force of explosive detonation;

Fig. 13 is a side elevational view of the cap structure of Fig. 12; and

Fig. 14 is a plan view of a shaped charge cap, similar to that of Fig. 12 and representing an alternative embodiment showing an additional optional fracture groove defined in the central portion of the cap.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENT

Referring now to the drawings and first to Figs. 1 and 2, an encapsulated explosive shaped charge for casing perforation of wells, which is constructed in accordance with the principles of the present invention ,is shown generally at 10. The encapsulated explosive shaped charge 10 is defined by a charge case 12 which is preferably composed of steel, but which may be composed of any other suitable metal or non-metal material having sufficient structural integrity for the intended purpose. The rear end 14 of the charge case 12 defines a rear projection 16 having an aperture 18 through which is threaded a length of explosive primacord which is selectively fired, such as by an electrically initiated detonating cap, not shown, and which initiates the explosive shaped charges within the encapsulated explosive shaped charge 10 and also initiates each of the other encapsulated explosive shaped charges of the perforating gun. If desired, the projection 16 may define a slot or any other suitable recess for receiving a length of explosive initiating primacord. The charge case 12 defines wall structure 20 which is of generally circular configuration at the front end 22 and which defines an essentially funnel shaped internal wall surface 24 that may be of curved configuration or of conical configuration so as to define an internal charge case receptacle 26 of a desired concave configuration for the shaped explosive charge that is located therein. The shaped explosive charge may be composed of any of a number of suitable explosive compositions that are considered suitable for use in well casing perforating guns. For example, explosive compositions such as RDX, HNS, PYX, HMX and HTX are commonly used in well perforation shaped charges. The term "shaped" is intended to mean any suitable explosive composition which is concave shaped to define an explosive jet focusing capability so that detonation of the explosive composition will generate a, concentrated and specifically oriented explosive jet having the capability for penetrating the steel material of a well casing and for penetrating through the cement annulus about the well casing and well into the formation to be produced. The configuration of the wall structure of the charge case also assists the explosive composition in focusing the

energy of the explosive charge so as to develop a well defined and specifically oriented explosive jet.

The front end 22 of the charge case 12 defines a generally circular and preferably planar surface 28 which functions as a sealing surface and which also functions as a structural support surface for a front end cap member 30. The front end cap 30 is preferably composed of ceramic material which, upon detonation of the shaped charge, will be broken into a multiplicity of small pieces or particles that will fall to the bottom of the wellbore and will not represent a hazard to various well servicing operations that are subsequently carried out. The ceramic material of the front end cap will essentially be rendered to granular form not unlike sand by detonation of the explosive composition, while the steel charge case will be fractured by the explosive detonation into a large number of small case sections that will not represent an obstruction within the wellbore. A generally circular region 32 of the end cap 30 is normally disposed in face to face engagement with the surface 28 as shown in Fig. 1 and in greater detail in Fig. 2.

It is desirable to establish a seal between the charge case 12 and the end cap 30 to prevent pressurized well fluid from entering the internal chamber 26 of the charge case. To accomplish this feature, the front cap 30 is provided with a generally circular seal recess 34 which is defined by a generally cylindrical recess surface 36 and a circular planar recess surface 38. When the end cap 30 is in assembly with the charge case 12, the planar end surface 28 also defines a surface of the seal recess 34. A generally circular sealing element 40, composed of elastomeric sealing material is located within the seal recess and is "activated", i.e., compressed by the end cap to effect interference sealing between the charge case and the end cap. The elastomeric sealing element 40 is preferably in the form of an O-ring seal and is of a greater cross-sectional dimension as compared with the spacing of the planar sealing surfaces 28 and 38. Thus, when the front cap 30 is seated on the charge case 12 with its surface 32 in supported face to face engagement with the planar end surface 28, the O-ring sealing element will be physically deformed from a circular cross-sectional configuration to the oval cross-sectional configuration shown in Fig. 2, thus causing

its compressive sealing engagement with the opposed planar surfaces 28 and 38. External pressure, such as that imposed by the pressure of well fluids, will drive the sealing element radially inwardly against the cylindrical surface section 36 of the seal recess, thus maintaining an effective seal to prevent ingress of fluid pressure into the internal chamber of the charge case and end cap assembly. At this point, it should be noted that the seal recess 34 is open at its outer periphery.

Even though the cap member 30 is sealed with respect to the circular front end 22 of the charge case 12 it may become necessary to vent or release any excess pressure that might build up within the internal charge case receptacle 26. For example, when a perforating gun is located within a well, especially if the well is deeply drilled, the surrounding formation can be at a substantially elevated temperature that the explosive composition of the internal shaped charge within the charge receptacle 26 may begin to liberate gas, a condition known as out-gassing. When this condition occurs, because the receptacle 26 has a relatively small dimension, gas pressure can build up quickly. In another example, an increase in the internal pressure of the charge case receptacle can also occur if wellbore gases migrate into the receptacle while the perforating gun is downhole. Additionally, should well fluid, particularly natural gas penetrate into the internal cavity of the charge, such as by penetrating through porous wall structure of the charge case or cap, the pressure within the charge case can be significantly elevated. If the perforating gun is then removed from the well in its unfired condition, the external pressure will be diminished from well pressure at depth to atmospheric pressure. When either of these conditions occurs, the internal pressure of the charge case receptacle can cause the front cap of the charge to be forcibly ejected, i.e., blown away, thus presenting a potentially dangerous situation. It will then be necessary to replace any charges that have become damaged in this manner. It is desirable therefore to provide individual encapsulated shaped casing perforation charges with means for releasing this excess internal pressure while at the same time maintaining a sealed condition between the charge case and the front cap with respect to ingress of well fluid into the internal receptacle of the charge case. In other words, it is desirable to provide the seal

between the charge case and the front cap with a check valving capability to permit bleeding of excess fluid pressure from the internal receptacle of the charge case and to prevent fluid pressure transmission across the seal in the opposite direction.

The pressure seal between the metal charge case and the ceramic cap may also be designed according to the alternative embodiments of Figs. 10 and 11. In Fig. 10 the charge case 21 defines a circular tapered surface 23 which cooperates with a circular oppositely tapered surface 25 of a ceramic charge cap 27 to define a circular seal groove at the juncture of planar surfaces 29 and 31 of the charge case and ceramic cap, respectively. In Fig. 11, the metal charge case 33 defines a circular seal recess 35 which contains a compression type elastomer O-ring seal 37. The ceramic cap 39 defines a circular planar surface 41 which cooperates with the circular seal recess surfaces of the seal recess 35 to form a circular seal groove containing the sealing element 37.

According to the principles of the present invention a pressure bleeding arrangement is defined by a thermoplastic, yieldable pressure release ring 42 which, when viewed in cross-section as shown in Fig. 2, includes a generally cylindrical intermediate section 44, an angulated or tapered front cap retainer section 45 and a generally frusto-conical or tapered rear section 46. The angulated or tapered front cap retainer section 45 engages a tapered front end surface 47 of the front end cap 30 as shown in Fig. 4 and assists the crimp ring in retention of the front end cap against internal charge pressure. The generally cylindrical intermediate section 44 of the pressure release ring 42 defines an inner cylindrical surface section 48 which, when the yieldable pressure release ring 42 is in assembly with the charge case and front cap member, is disposed in engagement with a generally cylindrical outer peripheral surface 50 of the front cap 30. The generally frusto-conical or tapered lower section 46 is integral with the generally cylindrical upper section 44 and is disposed in essentially angular relation therewith. The angulated lower section 46 is adapted to be received with a correspondingly angulated outer peripheral recess 52 which is defined by the front end 22 of the charge case 12. The yieldable pressure release ring 42 defines at least one and preferably a plurality of pressure relief slots, grooves or

channels 54 having the front ends thereof defined by the generally cylindrical upper portion 44 of the yieldable pressure release ring 42 and having the rear ends thereof extending to the rear end 56 of the ring 42.

The yieldable pressure release ring 42 is retained at the position shown in Fig. 2 by a crimp ring 60 which is shown in the crimped condition thereof in Fig. 2. The crimp ring encircles the elastomer seal ring as well as the thermoplastic, yieldable pressure release ring. The crimp ring defines an intermediate section 62 which is positioned in encircling relation about the generally cylindrical intermediate section 44 of the yieldable pressure release ring 42 and secures the yieldable pressure release ring intimately about the outer peripheral surface 50 of the front cap 30. The crimp ring 60, in its crimped condition, also has an inclined or generally conical front section 61 which is crimped about an outer peripheral section of the front cap 30 and retains the end cap firmly seated in face to face relation on the planar end surface 28 of the charge case 12. The generally conical section 61 also secures the circular tapered front section 45 of the yieldable pressure release ring in engagement with the tapered front end surface 47 of the front end cap 30. The crimp ring 60, in its crimped condition, further has an inclined or generally conical rear end section 66 which secures the rear end section 46 of the thermoplastic pressure release ring 42 in inclined orientation and seated within the correspondingly inclined outer peripheral groove 52 of the charge case.

It should be borne in mind that both the pressure release ring 42 and the crimp ring 60 may be of essentially cylindrical configuration prior to crimping of the crimp ring as shown in Fig. 3. The process of crimping the crimp ring, in this case, will deform the pressure release ring from its essentially cylindrical configuration to the angulated cross-sectional configuration shown in detail in Figs. 2 and 4 and will force the rear end of the thermoplastic pressure release ring into the angulated outer peripheral recess 52 at the front end of the charge case.

Referring now to Fig. 5, the partial sectional view illustrates release of excess internal gas pressure from the encapsulated shaped charge. As mentioned above, excess charge case pressure can be due to heat induced out-gassing of its explosive

composition or due to migration of gas pressure of a well into the charge case. During pressure release the internal pressure build-up within the internal chamber of the charge case will act on the O-ring sealing member 34 as shown by pressure induced force arrows, causing it to be expanded or moved radially outwardly. At a predetermined elevated internal pressure, portions of the O-ring seal material will be driven into the front end sections of the relief grooves or slots 64. At designed relief pressure, the O-ring seal will have been yielded radially outwardly sufficiently that the excess pressure will bypass the O-ring seal and will be relieved into the relief grooves or slots 64 of the pressure relief member as shown by flow arrows. The relieved pressure from the internal receptacle 26 may then displace the rear end of the pressure relief ring as shown, allowing the excess pressure to be relieved into the environmental medium surrounding the encapsulated shaped charge. Alternatively, the relieved charge pressure can be simply relieved to the atmosphere or to the surrounding environment via the bleed slots of the thermal relief ring. Obviously, the excess internal pressure condition will change, depending whether the encapsulated shaped charge is located at depth within the well and subject to well pressure or whether it is subject to atmospheric pressure. Preferably, pressure relief will occur slowly as the unfired perforating gun is being moved through the tubing string to the surface, so that pressure bleeding will not occur in the presence of workers at the rig floor. This automatic pressure relieving capability of the encapsulated shaped charge will prevent forcible ejection of the front end cap 30 from the charge case in the event the perforating gun containing the shaped charge is removed from the well in unfired condition.

In the event the encapsulated shaped charge is subjected to extreme heat, such as in the case of a fire that occurs during its storage or transportation, the explosive composition of the internal shaped charge will initially begin out-gassing and internal pressure within the internal receptacle will build up rapidly. Obviously, with explosive materials, a significant increase in pressure and the presence of significant heat can cause the explosive material to detonate. If the condition of elevated temperature occurs in absence of elevated internal pressure of the encapsulated shaped

charge, the explosive composition will have the tendency to burn rather than detonate. Thus, it is desirable to ensure against significant build-up of internal pressure within the encapsulated shaped charge when the shaped charge is subjected to elevated heat. To accomplish this feature, the pressure relief ring 42 may be composed of thermoplastic polymer material so that it will essentially melt when the encapsulated shaped charge is subjected to a condition of heat that is sufficiently elevated to cause rapid out-gassing of the explosive composition of the internal shaped charge. When the pressure relief ring melts, it will easily yield to internal pressure build-up and will vent excess pressure to the external environment, i.e., typically the atmosphere. The explosive composition will be burned, but, in the absence of sufficient pressure, it will not detonate and cause explosive damage to the surrounding environment.

Referring now to Figs. 6-9, an alternative embodiment of the present invention is shown wherein an encapsulated shaped charge shown generally at 70 in Fig. 6 incorporates a charge case 72 that may be essentially identical with the charge case 12 of Fig. 1. An end cap member 74, preferably composed of ceramic material, is seated in face to face relation with the circular front end 76 of the charge case wall 78 and defines a circular seal recess 80 within which is located a circular interference sealing member 82. The end cap 74 may also define an abrupt circular shoulder 86 or the end cap 74 may be of essentially the same geometry as the end cap 30. A crimp ring 88, shown prior to being crimped in Fig. 7 defines an end flange 90 which is adapted to seat on the circular shoulder 86 of the end cap 74 as shown in detail in Fig. 9. The crimp ring 88 defines a plurality of pressure relief slots or grooves 92 which extend from a region of the crimp ring adjacent to and circumferentially about the circular seal recess 80 to the rear end of the crimp ring. When the crimp ring is crimped its rear end section will be deformed from the essentially cylindrical configuration of Fig. 7 to the generally conical condition shown in Fig. 9, thus causing the rear end section to enter the inclined outer peripheral crimp ring recess of the charge case wall 78.

When internal charge case receptacle pressure build-up occurs when the encapsulated shaped charge is located at depth within a well and the internal pressure becomes sufficiently great that relief of excess internal pressure is needed, the

elastomeric O-ring sealing member will be moved radially outwardly by the excess internal pressure, thus relieving excess pressure via the pressure relief grooves or slots 92 and preventing the end cap 74 from being blown away violently by excess internal pressure if the encapsulated shaped charge is removed from a well in unfired condition.

For relief of excess pressure occurring due to excessive heat, such as in the case the encapsulated shaped charge is subjected to a fire, the crimp ring 88 is composed of a low temperature melting alloy which will melt and yield well below the temperature at which the explosive composition of the shaped charge will have any tendency toward detonation. The melting point of the low temperature alloy can be designed to suit the out-gassing temperature of the particular explosive composition that is utilized for the explosive charge, i.e., approximately 400 degrees F for RDX and 500 degrees F for HNS or PYX, which are explosive compositions that are common in the shaped charges for well casing perforation.

Referring now to Figs. 12-14, alternative embodiments of the present invention are shown which permit metal such as carbon steel, heat treated steel, cast iron or steel, bronze, plastics, composite materials or any other suitable material to be used to define a shaped charge cap structure that is designed and manufactured for controlled fracturing when the explosive material of well perforating guns is detonated. In the plan view of Fig.12 and the side elevational view of Fig. 13, a shaped charge cap shown generally at 100 is of circular, essentially domed configuration, though its configuration is not considered critical to the present invention. The cap structure 100 may be of any of a number of acceptable shapes without departing from the spirit and scope of the present invention. The shaped charge cap 100 defines a plurality of generally radially oriented fracture grooves 102 which extend from the central portion of the cap structure to side portions of the cap structure as shown and thus define predetermined stress concentration points or lines throughout the cap structure. The number and orientation of the fracture grooves is designed according to the character of the material to be fractured. The fracture grooves may be disposed in generally radially oriented relation as shown in Figs. 12-

14 or additionally transversely oriented fracture grooves may be employed as partially shown in Figs. 12 and 13 at 103. It is within the scope of the present invention to provide the cap 100 with stress concentrating features or fracture grooves of any suitable geometric design that enables the explosive jet of shaped charge detonation to fracture the cap into sufficiently small sections that will not impede the conduct of other well construction or servicing operations. This feature will permit the cap structure to be composed of a wide variety of materials such as any of a number of suitable metals, i.e., heat-treated carbon steels, cast iron, steel and suitable non-metal materials such as plastics, ceramic material and the like. The cap may also be composed of metal or non-metal composite materials if desired. When detonation of the shaped charge occurs, the forces of detonation of the explosive composition within the charge case will cause the cap structure to be fractured at least along the various radiating fracture lines or stress concentration points or lines 102 so that the cap will be fractured into a multiplicity of small sections according to the design of the stress concentration features. It should be borne in mind that additional fracture grooves may be formed in the cap structure which may be oriented other than radially, so that fracture of the cap structure into a multiplicity of small sections is ensured regardless of the material from which the cap is composed when the explosive jet of the shaped charge passes through the cap.

In the alternative embodiment of Fig. 14, the cap structure shown generally at 104 is shown to be essentially of the circular, domed configuration shown in Figs. 12 and 13. The cap 104 is also shown to be provided with a plurality of fracture grooves or stress concentration points 106 which radiate from the central portion of the cap to the circular edge of the cap essentially as described in connection with Fig. 12 and 13. Additionally, the cap structure 104 defines a generally circular fracture groove or stress concentration point or line 108 which is located centrally of the cap and thus enhances fracturing of the central portion of the cap into a multiplicity of small sections or particles responsive to passage of the explosive jet therethrough upon detonation of the shaped charge. It should be borne in mind that any suitable fracture grooves or stress concentration points or lines may be defined by a shaped charge cap

structure to ensure orderly, designed fragmenting thereof responsive to the force of detonation of the explosive charge. Thus, a wide variety of materials may be considered for construction of a shaped charge cap structure which would not ordinarily be acceptable.

In view of the foregoing it is evident that the present invention is one well adapted to attain all of the objects and features hereinabove set forth, together with other objects and features which are inherent in the apparatus disclosed herein.

As will be readily apparent to those skilled in the art, the present invention may easily be produced in other specific forms without departing from its spirit or essential characteristics. The present embodiment is, therefore, to be considered as merely illustrative and not restrictive, the scope of the invention being indicated by the claims rather than the foregoing description, and all changes which come within the meaning and range of equivalence of the claims are therefore intended to be embraced therein.

WE CLAIM:

1. An encapsulated shaped charge for well casing perforation, comprising:

a shaped charge case defining an internal receptacle having a shaped explosive charge therein, said shaped charge case having a closed end and an open end;

a cap member being in assembly with said shaped charge case at said open end and defining an assembly joint therewith and defining a closure for said internal receptacle;

a seal member being located at said assembly joint and establishing sealing between said shaped charge case and said cap member;

a pressure release member substantially encircling said assembly joint and defining at least one relief slot for bleeding excess internal pressure from said internal receptacle; and

a crimp ring securing said cap member to said shaped charge case.

2. The encapsulated shaped charge of claim 1, comprising:

said cap member being composed of ceramic material and, upon detonation of said shaped explosive charge, being fractured into a multiplicity of very small pieces.

3. The encapsulated shaped charge of claim 1, comprising:

said shaped charge case being composed of metal material; and

said cap member being composed of ceramic material and, upon detonation of said shaped explosive charge, being fractured into a multiplicity of very small pieces.

4. The encapsulated shaped charge of claim 1, comprising:

said shaped charge case defining a generally circular sealing and cap seating end surface;

said cap member defining a generally circular seal recess and having a generally circular portion thereof seated on said generally circular sealing and cap seating end surface; and

said seal member being located within said generally circular seal recess and having sealing engagement with said generally circular sealing and cap seating end surface.

5. The encapsulated shaped charge of claim 4, comprising:

said seal member being an elastomeric O-ring seal of greater dimension as compared with the dimension of said generally circular seal recess and being compressed between said cap member and said generally circular sealing and cap seating end surface upon crimping of said crimp ring.

6. The encapsulated shaped charge of claim 4, comprising:

said generally circular seal recess having an outer peripheral opening permitting internal pressure induced radial movement of said seal member for releasing excess internal pressure from said internal receptacle.

7. The encapsulated shaped charge of claim 1, comprising:

said shaped charge case defining an outer peripheral crimp ring groove; and

a circular portion of said crimp ring being received within said outer peripheral crimp ring groove upon crimping thereof.

8. The encapsulated shaped charge of claim 7, comprising:

said outer peripheral crimp ring groove being defined in part by a generally frusto-conical surface; and

a generally circular portion of said crimp ring being received in substantially engaging relation with said generally frusto-conical surface of said crimp ring groove upon being crimped.

9. The encapsulated shaped charge of claim 1, comprising:

said pressure release member being of generally circular configuration and being disposed externally of said shaped charge case at said assembly joint and having at least a portion thereof interposed between said crimp ring and said assembly joint.

10. The encapsulated shaped charge of claim 1, comprising:

said pressure release member being composed of thermoplastic material and yielding responsive to predetermined charge pressure or heat for releasing excess pressure from said shaped charge.

11. An encapsulated shaped charge for well casing perforation, comprising:

a shaped charge case defining an internal receptacle having a shaped explosive charge therein, said shaped charge case having a closed end and an open end;

a cap member being in assembly with said shaped charge case at said open end and defining an assembly joint therewith and defining a closure for said internal receptacle;

a seal member being located at said assembly joint and establishing sealing between said shaped charge case and said cap member; and

a crimp ring securing said cap member to said shaped charge case.

12. The encapsulated shaped charge of claim 11, comprising:

said crimp ring being composed of a material having low melting temperature for melting and releasing said cap member from said charge case in the event said encapsulated shaped charge is subjected to the low melting temperature.

13. The encapsulated shaped charge of claim 12, comprising:

said low melting temperature material having a melting temperature substantially conforming to the out-gassing temperature of the explosive composition of said shaped explosive charge.

14. The encapsulated shaped charge of claim 11, comprising:

said crimp ring defining at least one vent slot in communication with said assembly joint for venting out-gassing pressure from said encapsulated shaped charge.

15. The encapsulated shaped charge of claim 11, comprising:
said cap member being composed or ceramic material and, upon detonation of said shaped explosive charge, being fractured into a multiplicity of very small pieces.

16. The encapsulated shaped charge of claim 15, comprising:
said shaped charge case being composed of steel.

17. The encapsulated shaped charge of claim 10, comprising:
said crimp ring being physically deformed by crimping to establish retaining engagement with said shaped charge case and said cap member.

18. An encapsulated shaped charge for well casing perforation, comprising:
a shaped charge case composed of a non-ceramic material;
said shaped charge case having an open end;
a cap member being composed of a ceramic material; and
said cap member being attached to said shaped charge case at said open end.

19. The encapsulated shaped charge of claim 18, wherein:
said shaped charge case is composed of a metallic material.

20. An encapsulated shaped charge for well casing perforation, comprising:
a shaped charge case having an open end;
a cap member being attached to said shaped charge case at said open end; and
a ring securing said cap member to said shaped charge case.

21. The encapsulated shaped charge of claim 20, wherein said ring comprises a crimp ring.

22. The encapsulated shaped charge of claim 20, further comprising:

said shaped charge case including an internal receptacle;

a member defining at least one relief slot for bleeding excess pressure from said internal receptacle; and

said ring retaining said member.

23. An encapsulated shaped charge for well casing perforation, comprising:

a shaped charge case having an open end and defining an internal receptacle;

a cap member being attached to said shaped charge case at said open end; and

a member defining at least one relief slot for bleeding excess pressure from said internal receptacle.

24. The encapsulated shaped charge of claim 23, wherein:

said member being a pressure relief ring; and

a crimp ring securing said pressure relief ring to said shaped charge case and said cap member and securing said shaped charge case and said cap member in assembly.

25. An encapsulated shaped charge for well casing perforation, comprising:

a shaped charge case defining an internal receptacle having a shaped explosive charge therein, said shaped charge case having a closed end and an open end;

a cap member being in assembly with said shaped charge case at said open end and defining an assembly joint therewith, said cap member defining a closure for said internal receptacle; and

a plurality of stress concentration points being defined by said cap member for assuring designed fracturing thereof along said stress concentration points responsive to detonation of said shaped explosive charge.

26. The encapsulated shaped charge of claim 25, comprising:

a plurality of fracture grooves being defined by said cap member and defining said plurality of stress concentration points.

27. The encapsulated shaped charge of claim 26, comprising:
said cap defining a central region and an edge region; and
said plurality of fracture grooves being disposed in radiating orientation and extending from said central region to said edge region.

28. The encapsulated shaped charge of claim 26, comprising:
said cap defining a central region and an edge region; and
at least one of said plurality of fracture grooves being of generally annular configuration and being substantially centered within said central region, and a plurality of said fracture grooves being disposed in radiating orientation and extending from said central region to said edge region.

29. The encapsulated shaped charge of claim 25, comprising:
said cap being composed of metal; and
said plurality of stress concentration points being defined by a plurality of fracture grooves being defined in said cap and being oriented for fracture of said cap along said fracture grooves responsive to detonation of said encapsulated shaped charge.

30. A method of assembling an encapsulated shaped charge for well casing perforation, comprising:
providing a shaped charge case composed of a non-ceramic material, said shaped charge case having an open end;
providing a cap member composed of a ceramic material; and
attaching said cap member to said shaped charge case at said open end.

31. The method of claim 30, wherein said shaped charge case is composed of a metallic material.

32. A method of assembling an encapsulated shaped charge for well casing perforation, comprising:
providing a shaped charge case having an open end;
providing a cap member and a ring; and
attaching said cap member to said shaped charge case at said open end by securing said ring to said cap member and said shaped charge case.

33. The method of claim 32, wherein said attaching step comprises crimping said ring onto said shaped charge case and said cap member.

34. The method of claim 32, wherein said shaped charge case includes an internal receptacle, further comprising:
providing a member defining at least one relief slot for bleeding excess pressure from aid internal receptacle; and
attaching said member to said shaped charge case and said cap member.

35. A method of assembling an encapsulated shaped charge for well casing perforation, comprising:
providing a shaped charge case having an open end and an internal receptacle;
providing a cap member and a member defining at least one relief slot for bleeding excess pressure from said internal receptacle; and
attaching said cap member to said shaped charge case at said open end by securing said member to said cap member and said shaped charge case.

36. The method of claim 35, wherein said attaching step comprises crimping said member onto said shaped charge case and said cap member.

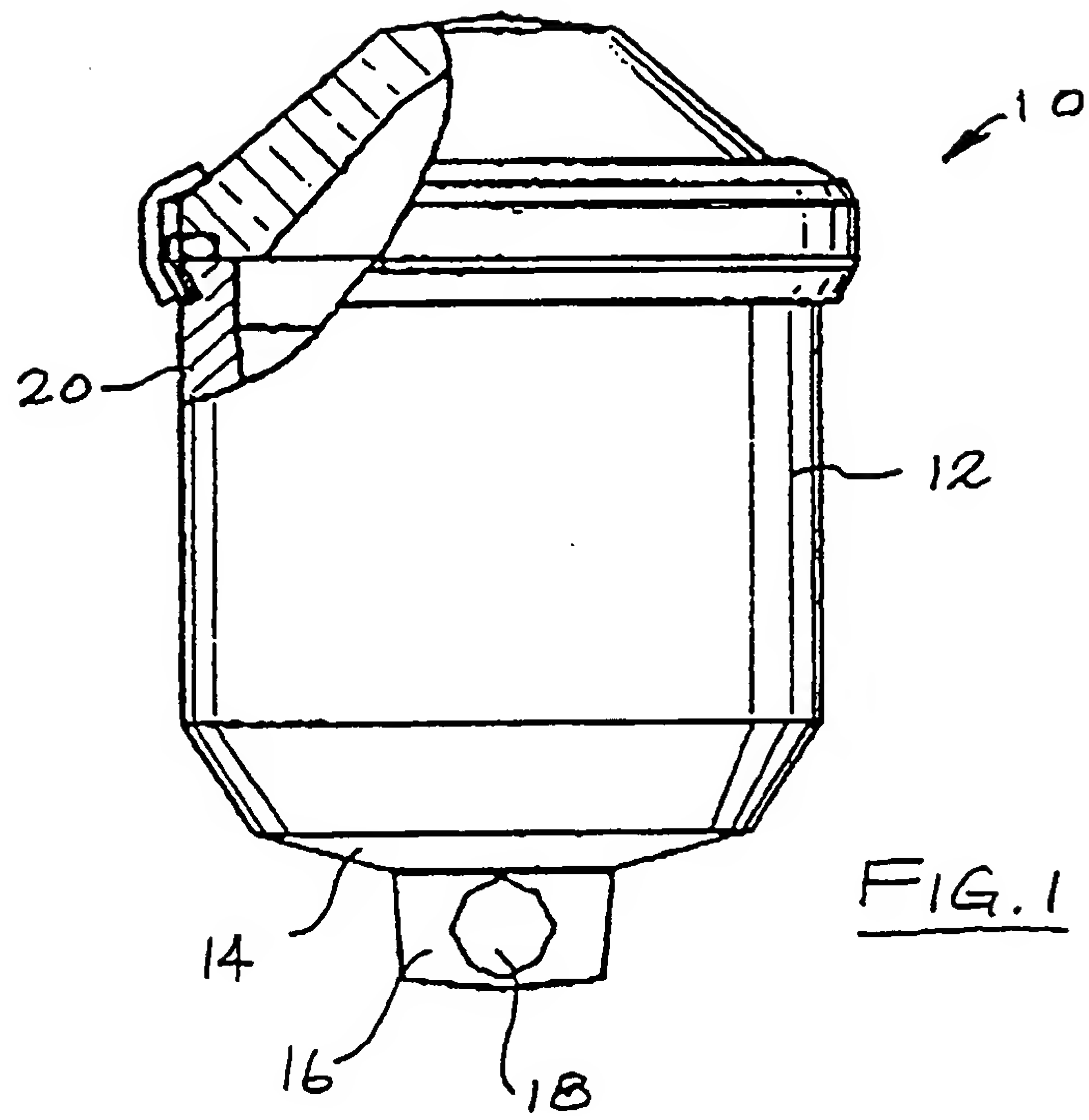

FIG.1

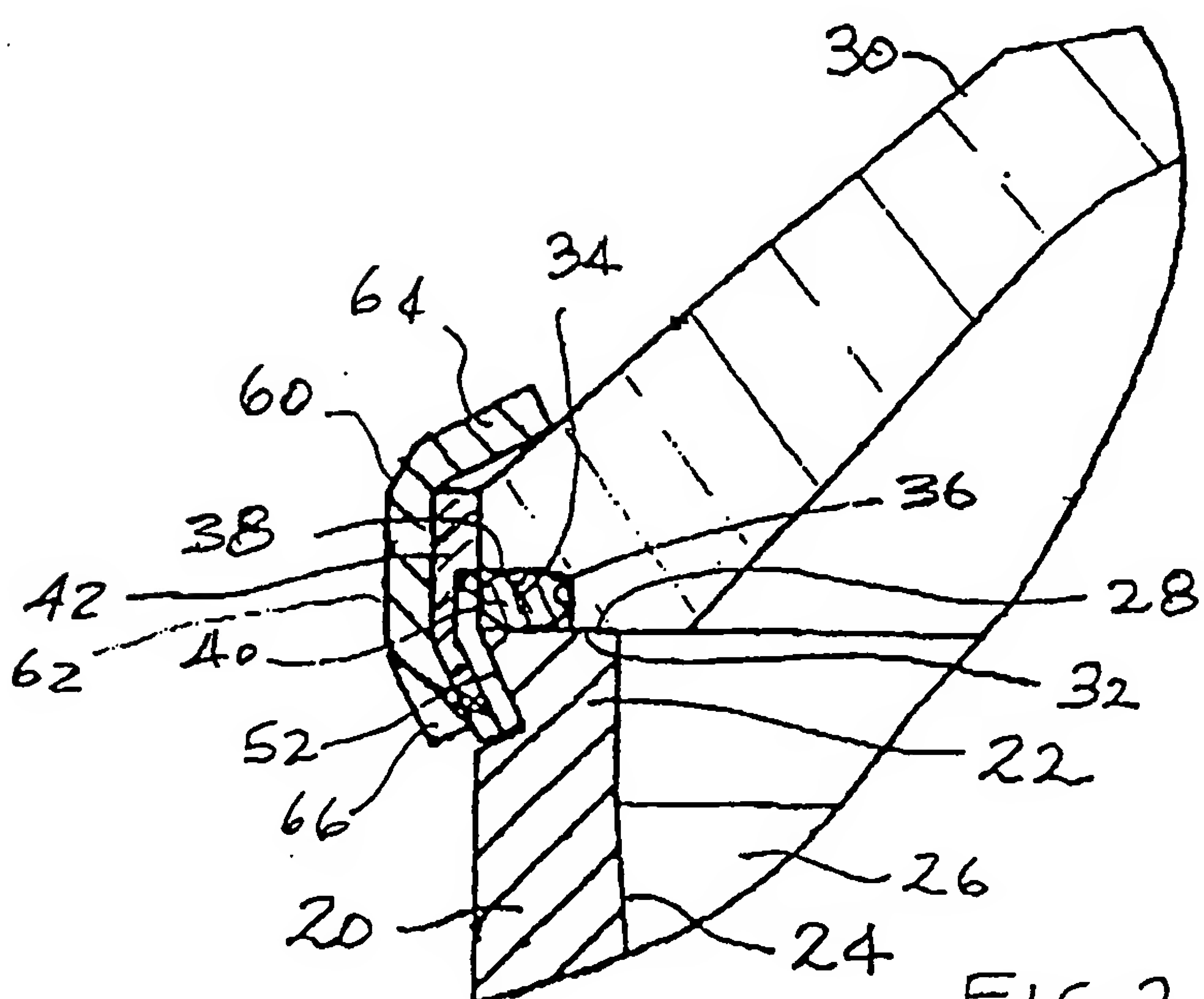

FIG.2

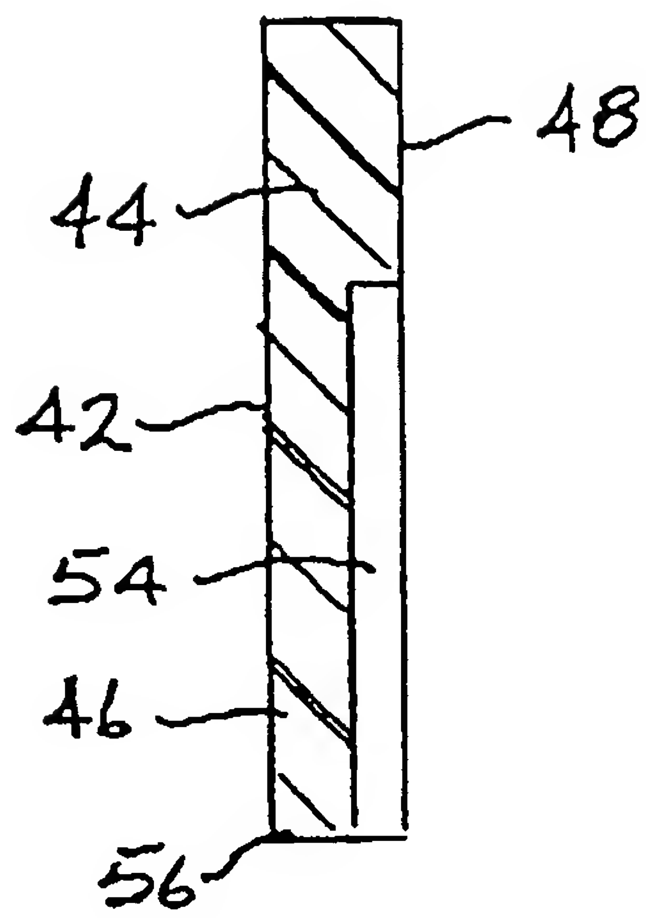

FIG. 3

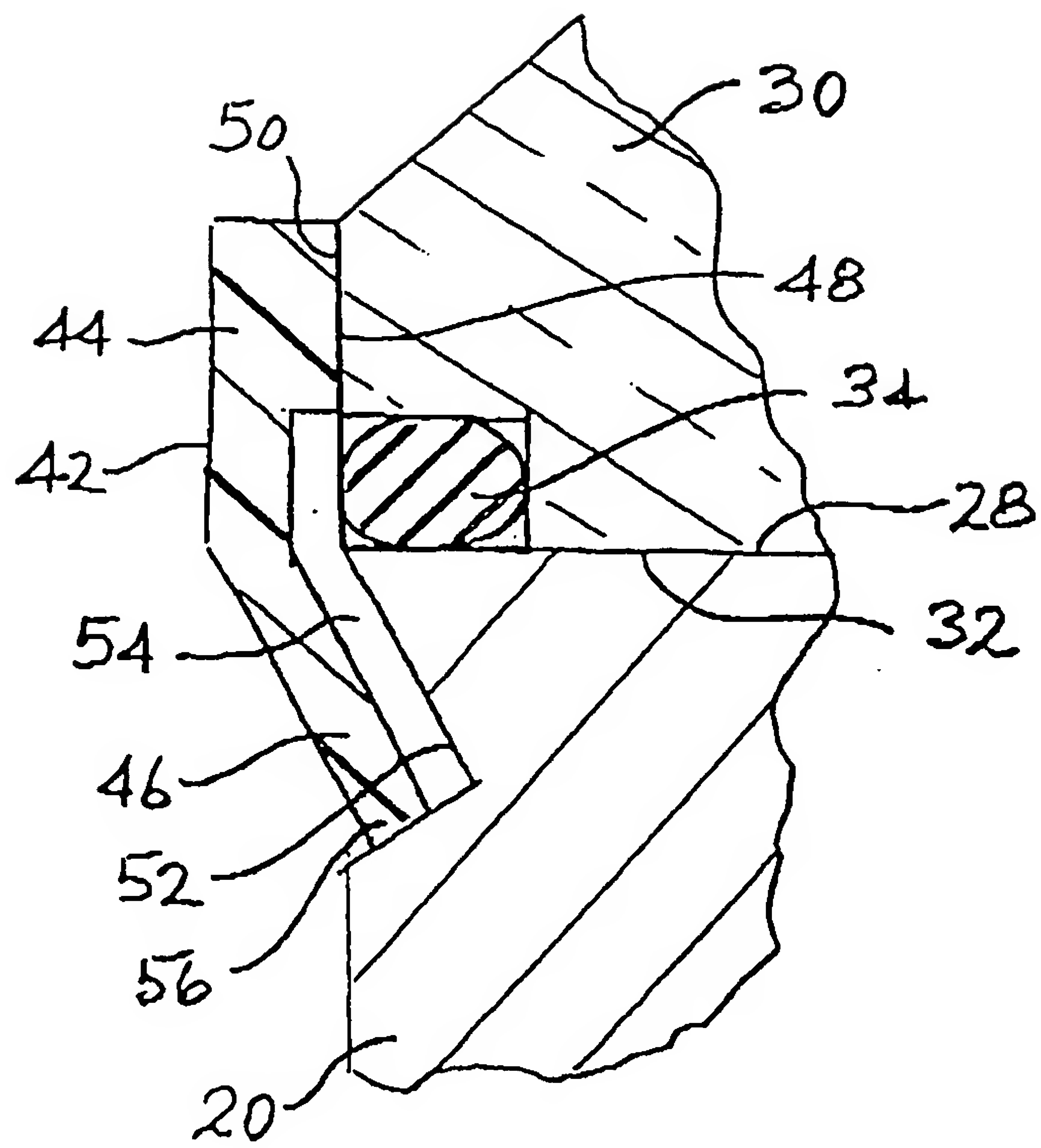

FIG. 4

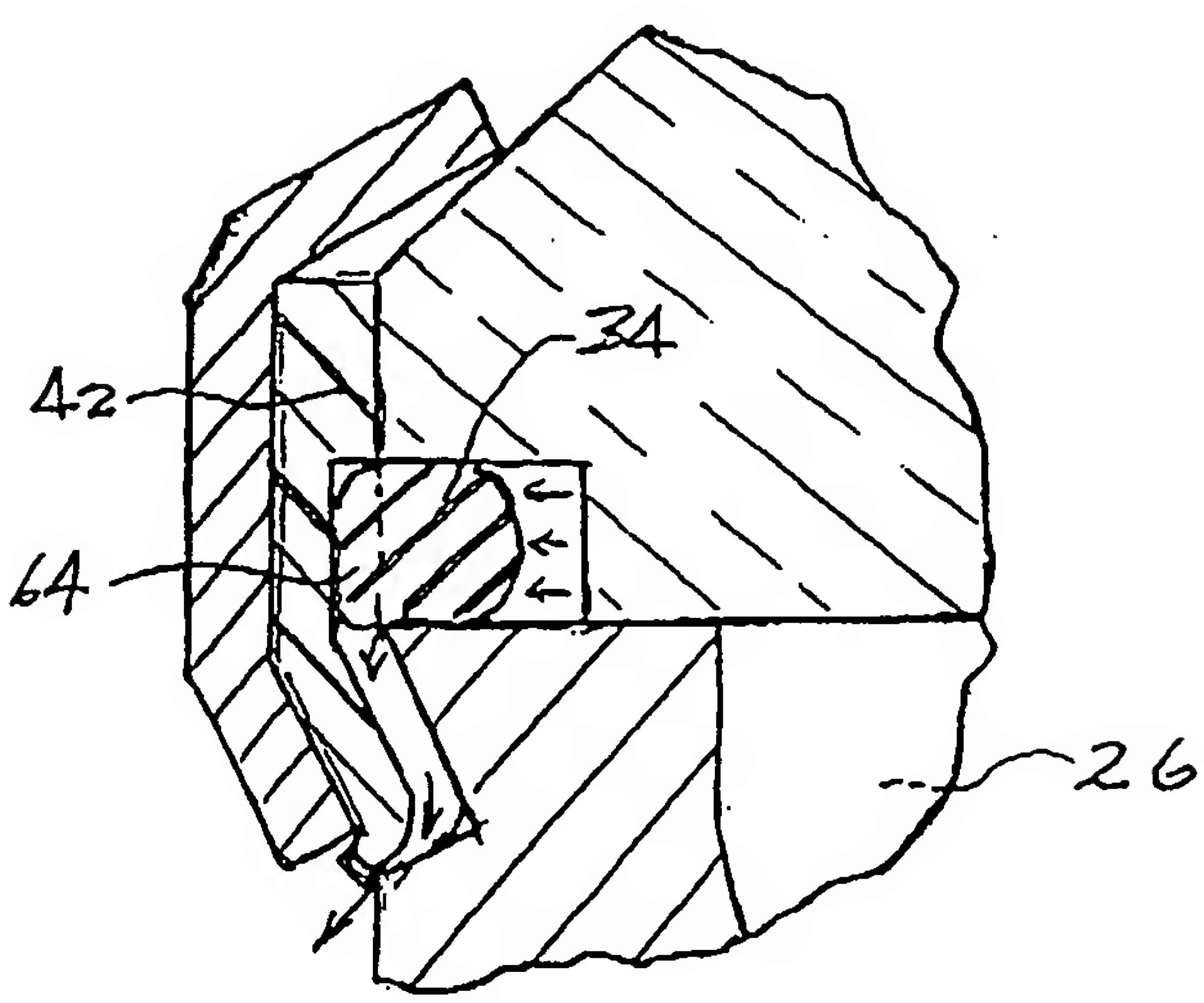

FIG 5

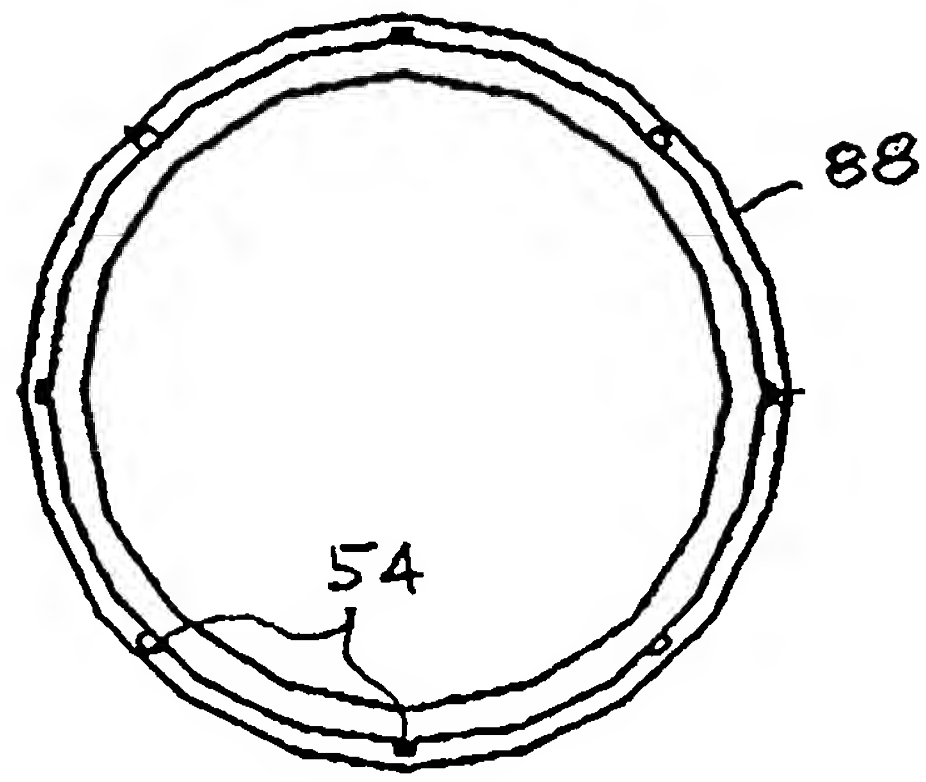

FIG.8

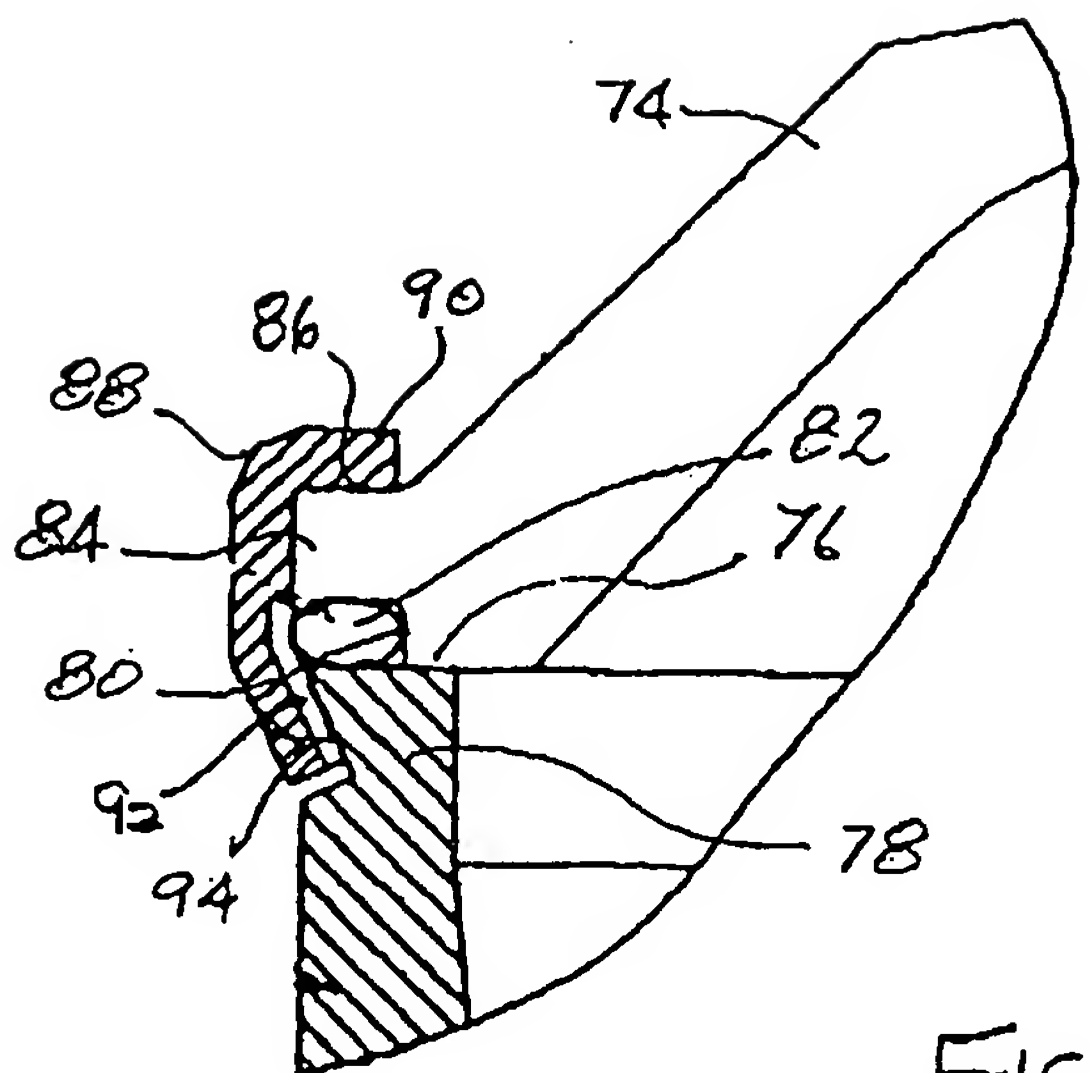

FIG. 9

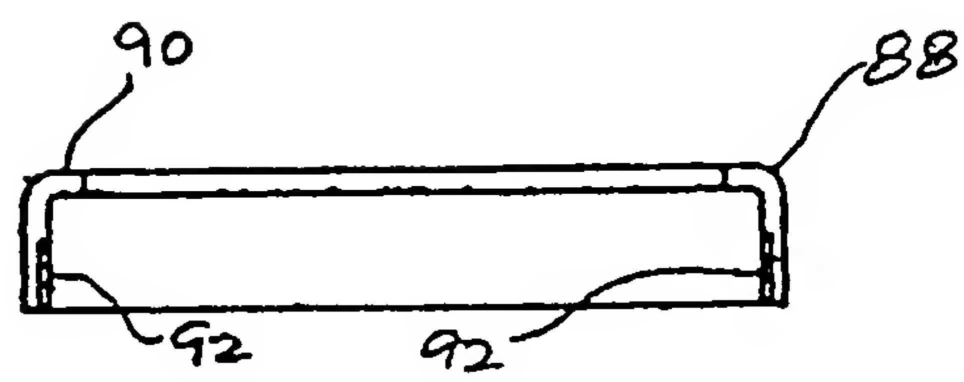

FIG. 7

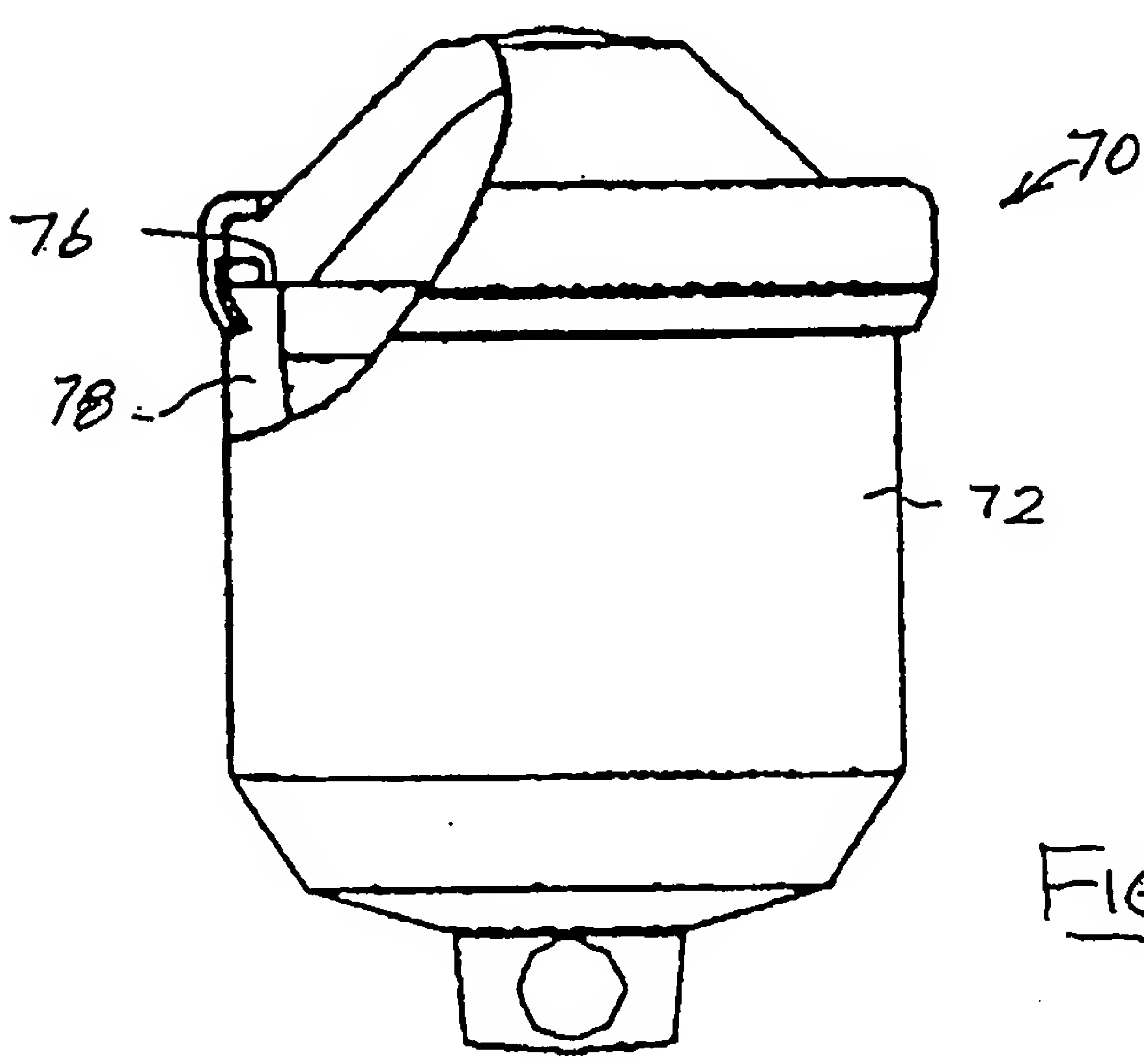

FIG. 6

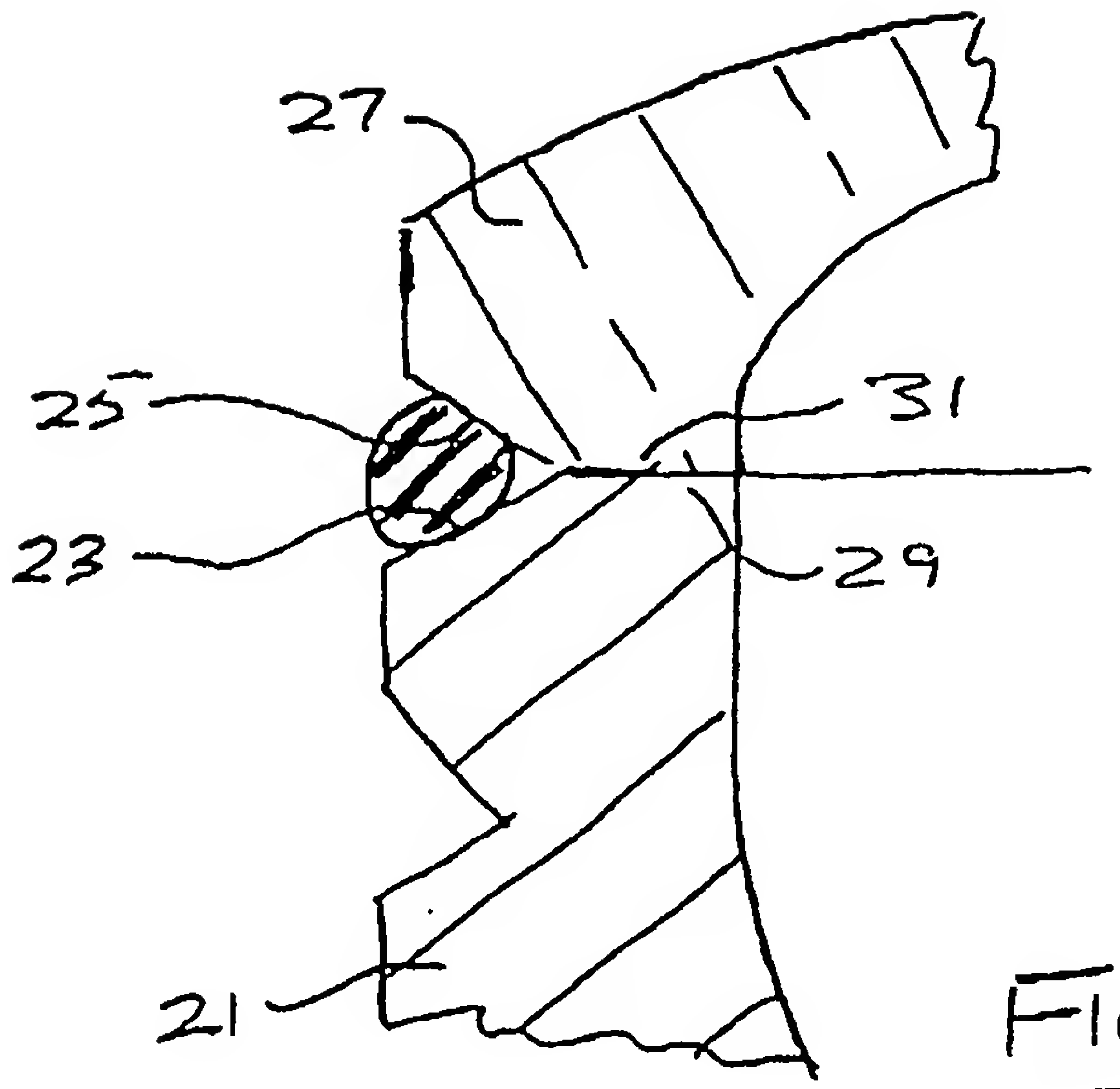

FIG. 10

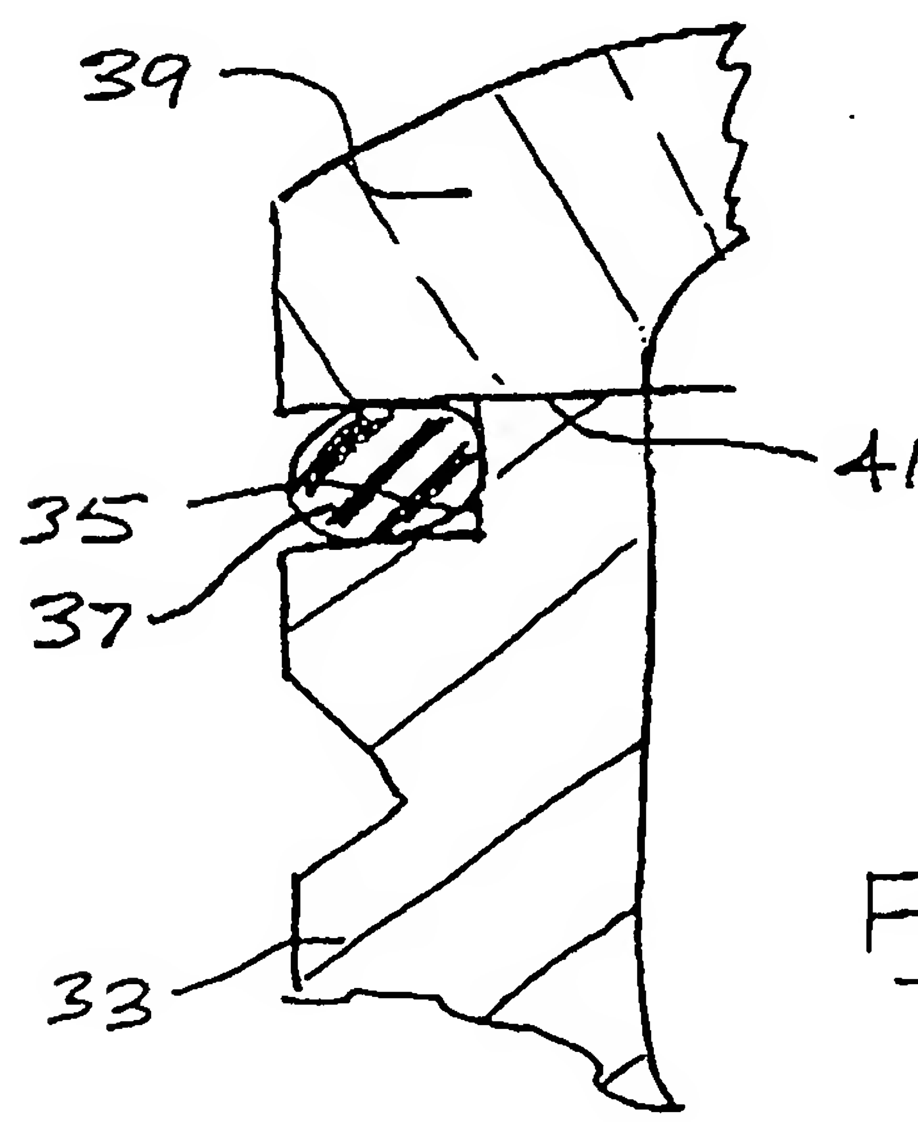

FIG. 11

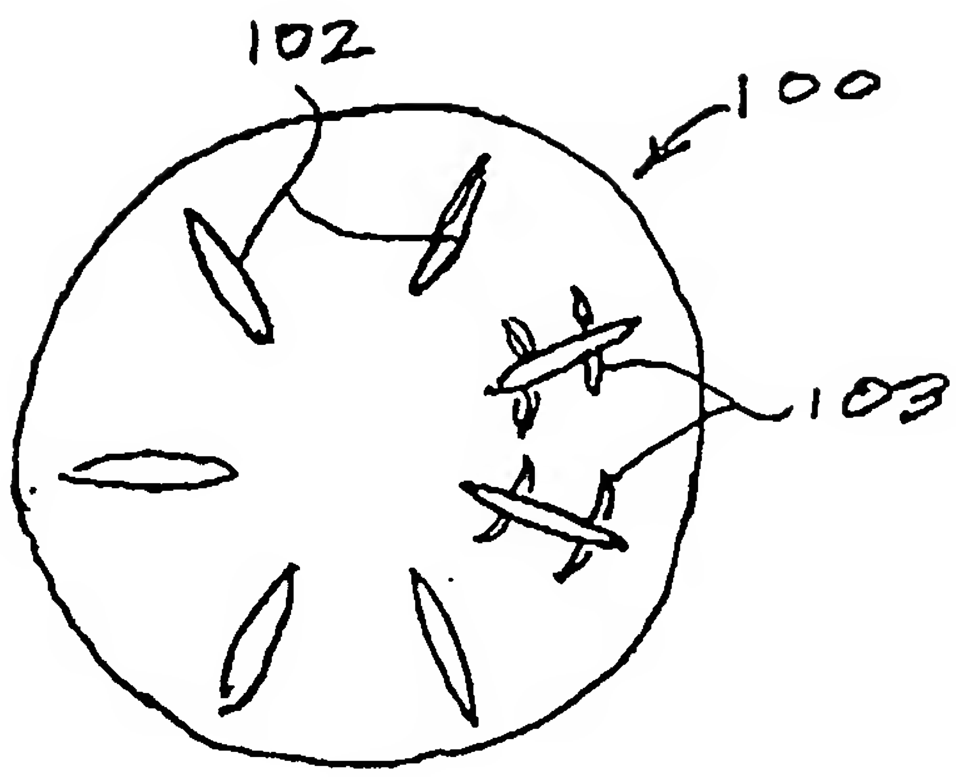

FIG 12

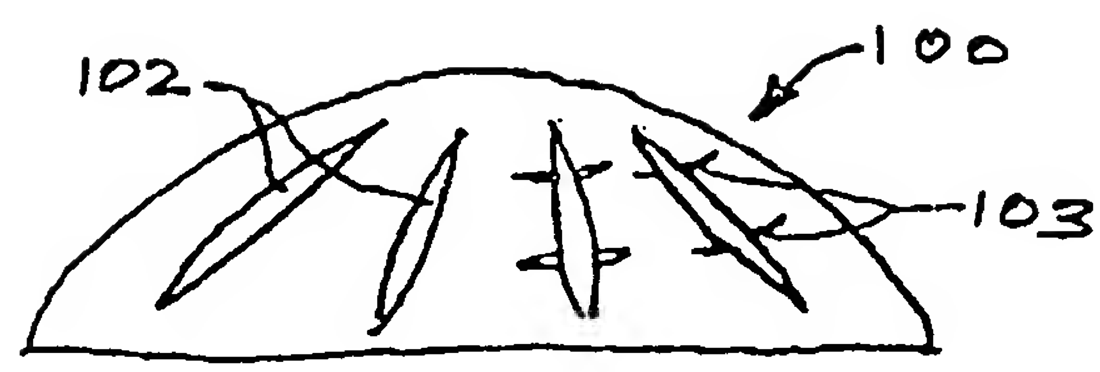

FIG 13

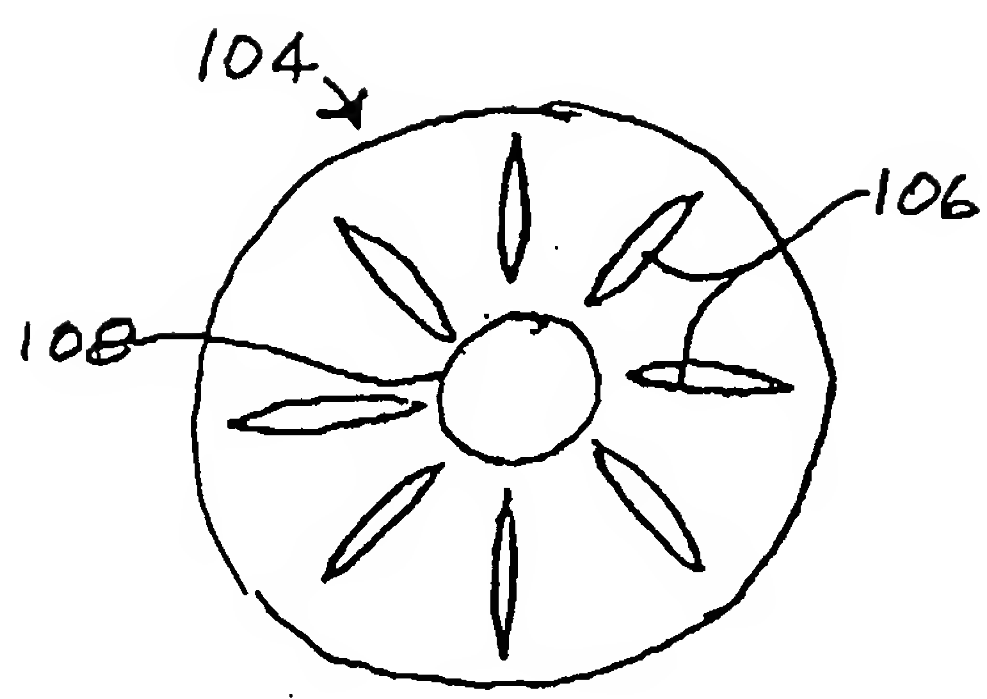

FIG.14

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US00/18486

A. CLASSIFICATION OF SUBJECT MATTER
IPC(7) : E21B 7/00; F42D 3/00
US CL : 175/4.6; 120/306
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
U.S. : 175/4.6; 120/306-310; 166/55, 55.1

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
APS shaped charge, ceramic, groove, metal, crimp

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --, E Y	US 6,098,707 A (PASTUSEK et al) 08 August 2000, col. 3, lines 7-20.	11,20-21,32-33 ------- 1, 4-10, 17, 21-24, 32-36
X --- Y	US 4,496,008 A (POTTIER et al) 29 January 1985, col. 5, lines 5-10.	18-19, 30-31 ----------- 2-3, 15-16
Y	US 4,881,445 A (HAYES) 21 November 1989, Fig. 9, Fig. 10.	1-10,14-17, 20-24, 32-36
Y	US 5,155,293 A (BARTON) 13 OCTOBER 1992, col. 3, lines 46-49.	12-13

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

* Special categories of cited documents:	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A" document defining the general state of the art which is not considered to be of particular relevance	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"E" earlier document published on or after the international filing date	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"&" document member of the same patent family
"O" document referring to an oral disclosure, use, exhibition or other means	
"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search 12 SEPTEMBER 2000	Date of mailing of the international search report 18 OCT 2000
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703) 305-3230	Authorized officer MEREDITH PETRAVICK Diane L Smith Telephone No. (703) 305-1113

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US00/18486

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5,088,557 A (RICLES et al) 18 Feburary 1992, Fig. 1 and Fig. 2.	25-29